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Use of Water Quality Indices for Water Quality Assessment in Small Island State: A Case Study in the Northern Aquifer of Mauritius

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Abstract

The Water Quality Index (WQI) is a single number that expresses water quality rating by aggregating the measurement of water quality parameters. The aim of this paper is to make an assessment of the Water Quality of the groundwater in the Northern Aquifer in Mauritius by making use of water quality indices using the Brown and his colleagues and the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) methods. Six water quality parameters were used to determine the WQI at 16 different sampling stations within the northern aquifer. The two methods provided two different ratings; 'Good Water Quality' rating for the Brown and his colleagues method and 'Excellent Water Quality' rating for the CCME WQI method. The ratings obtained from both WQI indicate that the water is suitable for drinking purposes. This study shows that WQI can be a valuable tool for water administrators and policy makers for assessing and rating the suitability of the water for different uses.

Keywords: Northern Aquifer; water quality index; water quality; groundwater.

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1. Introduction

The Northern Aquifer is an important source of fresh water supply and 50% - 60% of potable water in the northern region comes from groundwater [1]. There are 140 boreholes in the northern aquifer, out of which 30 are used for domestic water supply and 110 for agricultural and industrial use [1]. The aquifer is heavily exploited due to the limited availability of surface water to meet the increasing water demand. Growing economic activities together with urbanization represent a high risk of groundwater contamination. Therefore it has become necessary to evaluate the water quality. The objective of this research is to represent a Water Quality evaluation of the Groundwater in the Northern Aquifer through the use of WQI. Through this paper, an effort has been made to display the composition and structure of two different WQI methods. The Mauritius Drinking Water Standard of 1996 [2] is used as reference for standard values for calculations.

Interpretation of complex water quality data is difficult to understand and to communicate during decision making process [3]. The WQI is a single number that rates the water quality by aggregating several water quality parameters (such as pH, Nitrate, TDS etc.) and usually the Higher score alludes to the better quality (Excellent, Good) and the lower score to degraded quality (Bad, Poor) [3] or it can be vice versa. Assembling the various parameters of the water quality data into one single number leads an easy interpretation of data, thus providing an important tool for management and decision making purposes. The purpose of an index is to transform the large quantity of data into information that is easily understandable by the general public [4] . WQI exhibits the overall water quality at a specific location and specific time based on several water quality parameters and it is an effective way to categorize the quality of water in order to assess its suitability for various uses. WQI are tools to determine conditions of water quality and thus like any other tool, require knowledge about principles and basic concepts of water and related issues [5]. It is a well-known method of expressing water quality that offers a stable and reproducible unit of measure which responds to changes in the principal characteristics of water [6]. In other words, WQI summarizes large amounts of water quality data into simple terms (e.g., excellent, good, bad, etc.) for reporting to management and the public in a consistent manner [3].

Several WQIs have been formulated to efficiently evaluate the overall water quality within a particular area [7].

The general WQI was developed by Brown and his colleagues in 1972 and improved by Deininger for the Scottish Development Department in 1975 [8]. Horton (1975) suggested that the various water quality data could be aggregated into an overall index [8]. Brown and his colleagues proposed multiplicative form of the index where weights to individual parameters were assigned based on a subjective opinion based on the judgement and critical analysis of the author. The weight assigned reflected a parameter's significance for a use and had considerable impact on the index [3] .

The WQI of the Canadian Council of Ministers of the Environment (CCME WQI) [9] is an index used in many countries and has also been endorsed by United Nations Environmental Program (UNEP) in 2007 as a model for Global Drinking Water Quality Index (GDWQI) [7]. CCME WQI compares observations to a benchmark instead of normalizing observed values to subjective rating curves, where the benchmark may be a water quality standard or site specific background concentration [10].The CCME WQI model provides a simplified way of interpreting water quality parameters so that they are easily understood by policy makers and the general public [7].

2. Materials & methods

In this study, the Brown and his colleagues and the CCME WQI methods were applied to evaluate the water quality status of the groundwater in the Northern aquifer by determining the Water Quality Indices for Drinking Water. The study was conducted on 16 selected boreholes sampling stations on the Northern Aquifer and was based on a dataset of six water quality parameters namely, pH, Turbidity, TDS, Nitrate, chloride and sulphate. The data was collected from The Central water Authority, and computed over a period of 6 months from January to June 2016. Water quality sampling locations are shown in Figure 1 & figure 2.

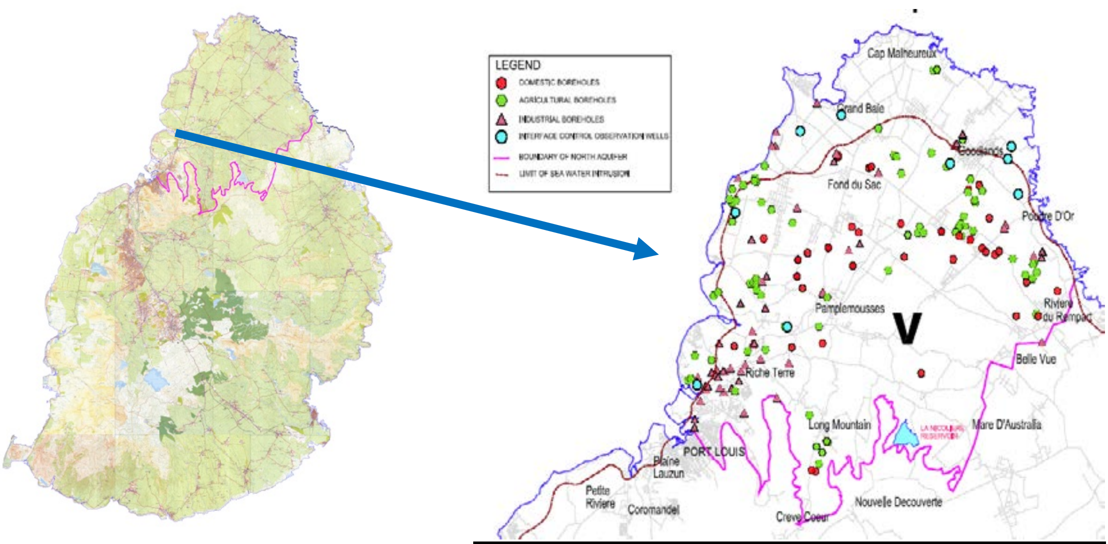

Figure 1 : Sampling Location in the Northern Aquifer

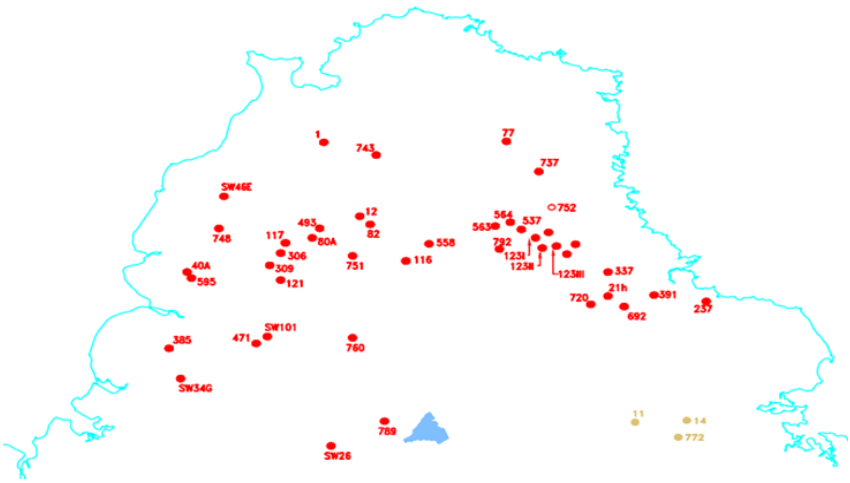

Figure 2 : Map showing location of boreholes with number

Table 1: Boreholes with Identification number

ID	BOREHOLE NAME	ID	BOREHOLE NAME	ID	BOREHOLE NAME
737	Beau Plateau BH737	**720**	Mon Loisir BH 720	551	Labourdonnais BH551
1	Fond du Sac BH 1	**306**	Morc. St Andre BH 306	12	Plaine des Papayes BH 12
654	Cottage BH 654	**82**	Belle Vue BH 82	748	Solitude BH 748
558	Mapou BH 558	**391**	Haute Rive BH391	337	Schoenfield BH 337
123	Poudre d'Or BH 123	**752**	L'Esperance BH 752		
385	Richeterre BH 385	**751**	La Louisa BH 751		

The average results for the 6 parameters, pH, Turbidity, TDS, Nitrate, Chloride and Sulphate were calculated over a period of 6 month from January to June 2016 for each borehole. The results are shown in table 2 below:

Table 2: Average results of analyses at different boreholes for period January to June 2016

BOREHOLE	pH	Turbidity (NTU)	TDS(mg/l)	Nitrate (mg/l)	Chloride (mg/l)	Sulphate (mg/l)
1. Beau Plateau BH737	6.74	0.3	240	42.24	49	12
2. Fond du Sac BH 1	6.74	0.3	307	39.16	56	23
3. Cottage BH 654	6.89	0.2	269	21.56	43	11
4. Mapou BH 558	6.71	0.3	222	35.64	71	26
5. Poudre d'Or BH 123	6.52	0.4	205	27.98	26	11
6. Richeterre BH 385	6.55	0.3	277	41.36	60	44
7. Mon Loisir BH 720	6.54	0.3	151	24.11	27	7
8. Morc. St Andre BH 306	6.66	0.4	188	21.03	34	9
9. Belle Vue BH 82	6.97	0.3	261	26.84	34	8
10. Haute Rive BH391	6.41	0.2	209	31.7	42	16
11. L'Esperance BH 752	6.78	0.2	203	33	37	16
12. La Louisa BH 751	6.73	0.2	256	29.19	35	13
13. Labourdonnais BH551	6.86	0.3	244	10.47	50	8
14. Plaine des Papayes BH 12	6.82	0.3	220	27.7	29	9
15. Solitude BH 748	6.70	0.3	238	22	55	19
16. Schoenfield BH 337	6.57	0.2	169	27.28	34	11
AVERAGE	**6.70**	**0.3**	**229**	**28.83**	**43**	**15**

2.1 Brown and his colleagues Method for calculating the Water Quality Index

The following equation was used for the Brown and his colleagues method:

Water Quality Index (WQI) = $\sum W_i q_i / \sum W_i$

Where,

q_i (water quality rating) = 100 X (V_a-Vi) / (V_s-V_i),

When V_a = actual value present in the water sample

V_i = ideal value (0 for all parameters except pH which are 7.0).

Vs = standard value.

If quality rating q_i =0 means complete absence of pollutants, While $0 < q_i < 100$ implies that, the pollutants are within the prescribed standard. When q_i >100 implies that, the pollutants are above the standards.

W_i (unit weight) = K / S_n 1

Where, K (constant) = $1/V_s1 + 1/V_s2 + 1/V_s3 + 1/V_s4 \ldots\ldots.. + 1/V_sn$

S_n = 'n' number of standard values.

Table 3: Water Quality Index & Status of water Quality – R. M. Chatterji [11]

Water Quality Index Level	Status of Water Quality
0-25	Excellent Water Quality
26-50	Good Water Quality
51-75	Poor Water Quality
76-100	Very Poor Water Quality
>100	Unsuitable for Drinking

2.2 Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) Method

The CCME WQI is based on a combination of three essential measures of variance (scope, frequency and amplitude). The combination of these measures of variance produces a single value (between 0 and 100), which classifies water quality into six respective categories: excellent, very good, good, fair, marginal and poor (Table 3). The CCME WQI computation technique has been described in detail by Abbasi and Abbasi (2012) [12]. The Canadian Water Quality Index (CWQI) Equation is calculated using three factors as follows:

$$WQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right)$$

Table 4: Water Quality Index

SN	Parameters	Observed values	Standard Value*	Unit Weight W_i	Quality Rating q_i	$W_i q_i$
1	pH	6.70	6.5 – 8.5	0.0531	60	3.186
2	Turbidity (NTU)	0.3	5	0.0744	6	0.4464
3	TDS (mg/l)	229	1000	0.000372	22.9	0.00851
4	Nitrate (mg/l)	28.83	50	0.00744	57.66	0.42899
5	Chloride (mg/l)	43	250	0.001488	17.2	0.00256
6	Sulphate (mg/l)	15	250	0.001488	6	0.00893
				$\sum W_i = 0.138288$	**$\sum q_i = 169.76$**	**$\sum W_i q_i = 4.08139$**
Water Quality Index = $\sum W_i q_i / \sum W_i =$ 29.51						

* The Standard values from the Drinking Water Standard of 1996 for Mauritius are used.

F_1 represents Scope: The percentage of parameters that exceed the guideline

$$F_1 = \left(\frac{\#\,\text{failed parameters}}{\text{Total}\,\#\,\text{of parameters}} \right) \times 100$$

F_2 represents Frequency: The percentage of individual tests within each parameter that exceeded the guideline

$$F_2 = \left(\frac{\#\,\text{failed tests}}{\text{Total}\,\#\,\text{of tests}} \right) \times 100$$

F_3 represents Amplitude: The extent (excursion) to which the failed test exceeds the guideline. This is calculated in three stages. First, the excursion is calculated

$$\text{excursion} = \left(\frac{\text{failed test value}}{\text{guideline value}} \right) - 1$$

NB: in the case of pH where a minimum and maximum guideline is given, the excursion equation must be run as above as well as in reverse i.e. guideline value/failed test value.

Second, the normalized sum of excursions (nse) is calculated as follows: $\text{nse} = \left(\dfrac{\sum \text{excursion}}{\text{total \# of tests}} \right)$

F_3 is then calculated using a formula that scales the nse to range between 1 and 100:

$$F_3 = \left(\frac{nse}{0.01\text{nse} + 0.01} \right)$$

Table 5: Water Quality Index & Status of Water Quality - CCME [9]

Water Quality Index Level	Status of Water Quality
95 – 100	Excellent
89 – 94	Very Good
80 – 88	Good
65 – 79	Fair
45 – 64	Marginal
0 – 44	Poor

Source: CCME (2001)

Table 6: Water Quality Index

SN	Parameters	Observed values	Standard Value*
1	pH	6.70	6.5 – 8.5
2	Turbidity (NTU)	0.3	5
3	TDS (mg/l)	229	1000
4	Nitrate as N (mg/l)	28.83	50
5	Chloride (mg/l)	43	250
6	Sulphate (mg/l)	15	250
	$F_1 = 0$		
	$F_2 = 0$		
	$F_3 = 0$		
Water Quality Index (WQI) = 100			

* The Standard values from the Drinking Water Standard of 1996 for Mauritius are used.

3. Results and discussion

The average results for the six months period, from January to June 2016 obtained from analysis of water sampled at the 16 selected boreholes in the northern aquifer are shown in Table 2. All the 6 parameters are within the permissible limits as per the Mauritius Drinking Water Standard of 1996. However, the nitrate level appears to be elevated. The boreholes at Beau Plateau BH737, Fond du Sac BH1 and Richeterre BH385 have the highest level of Nitrate reaching up to 42.24 mg/l. The Water Quality Index (WQI) is 29.5 for the Brown and his colleagues method which categorizes the groundwater of the northern aquifer as 'Good Water Quality' whereas for the CCME WQI method, the WQI is100 categorizing the water as 'Excellent Water Quality', showing the complete absence of pollutants. Both methods reveal that the groundwater is fit for human use. One of the WQI is based upon normalizing data parameter by parameter while the other compares observations to a benchmark. CCMEWQI compares observations to a benchmark, which is the Mauritius Drinking Water Standard of 1996 whereas the Brown and his colleagues is method is based on normalizing the observed values. Water quality index (WQI) is an effective way to communicate water quality. The study had some limitations. This study was based on cross-sectional study design only. However, it would have been better to collect samples throughout the year from January to December addressing seasonal variability. Only six parameters were chosen for the scope of this study. Therefore, the analysis has been limited to a few water parameters only due to resource constraints. Measuring other chemical parameters could be included in future studies. The limitations observed in this study highlight the insights for developing future scope for this research.

4. Recommendations

The development of water quality Indices in Mauritius will not only allow assessment of changes in water quality over time and space but also evaluate successes and shortcomings of water policies to protect water resources. The approach developed and outlined in this study can be used as a framework for tailoring other types of indices for water quality. The development of Water Quality Indices in Mauritius for the assessment of water quality can be used not only for drinking water and groundwater resources, but can also be adapted to inland surface water resources as it relates to both human and aquatic ecosystem health.

5. Conclusion

The Water Quality index is very useful tool for rating the quality of water in a specific area. The results obtained from both methods showed that the water quality in the Northern Aquifer of Mauritius is of good quality and is fit for human consumption. The weightage factor dictated the evaluation of WQI for the Brown and his colleagues method while benchmarking factor evaluated the WQI for the CCMEWQI method. Both methods can be used to develop Water Quality Indices in the small island state of Mauritius. Water Quality indices can be used as a tool to convey the information regarding the quality of water in an easy and understandable way to the public and policy makers. The Water quality indices can help to monitor the water quality and forecast preventive measures to be taken to maintain this high level of water quality and to ensure the safety of this valuable resource to the future generations.

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